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Final Report on the First Year Effort

AFOSR ~~Contract~~ 82-0056

" Three-Dimensional Interaction Effects in High
Speed Boundary Layer Flows "


Dr. G.R. Inger

University of Colorado at Boulder


Jan. 3 , 1983

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## 1. Introduction

The objective of this research is the basic theoretical investigation of three-dimensional pressure, skin friction and heat transfer disturbances in both laminar and turbulent boundary layer flows including viscous-inviscid interaction effects, separation and reattachment. A sound understanding of these phenomena is required in modern aerodynamic design analyses of high-speed flight vehicles.

The aforementioned need has led to a systematic basic research effort treating in parallel the twin problems of: (1) viscous-inviscid interaction with flow separation and/or attachment and (2) three-dimensional effects (including those due to streamwise vortices) in high-speed laminar and turbulent boundary layer flows. Such a study was initiated October 1, 1971 and has continued under AFOSR support. To date, it has been very successful both in solving a number of the target flow problems and in developing new ideas and tools[1-5]. In particular, a promising three-dimensional extension of successful non-asymptotic triple deck theory for two-dimensional shock - turbulent boundary layer interactions[6] was developed in collaboration with the Princeton Group's experimental studies [7,8] of the 3-D interaction phenomena illustrated in Fig. 1. This report summarizes our recent progress during the past year.

## 2. Summary of First Year's Progress

The project initiated in 1981 was understood to be a long range multi-year effort; in the initial year at the University of Colorado, we therefore concentrated on first strengthening and extending certain key aspects of our analytical triple-deck model approach in two-dimensional flow to expedite its subsequent application to the more general three-dimensional case. These activities have gone very well.

As part of a substantial involvement in the detailed research, the principal investigator familiarized himself with the Fast Fourier Transform ("FFT") technique and its operational mathematical content, since this may well be an important component in the actual solution techniques of the 3-D problem. Moreover, we have succeeded in extending Lighthill's[9] classical interaction theory (as well as Inger's generalization to turbulent flow[6]) to include wall suction or blowing effects; the results, which are in the process of final completion, provide for the first time a really fundamentally-based analytic theory for understanding and calculating these important effects in a variety of specific supersonic SBLI problems in either external aerodynamic or internal inlet flows. Comparisons will be made with available experimental studies such as those carried out at Cambridge, NASA-Lewis and (especially) at the University of Poitiers by LeBlanc, with whom the author has established collaboration under the aegis of an earlier NATO travel grant. We intend to prepare several major technical papers on this work for future technical meeting presentation and journal publication.

We have been fortunate to also find an approximate but accurate closed-form solution to the triple-deck equations including the turbulent case which describes all the major physical features of the interaction zone (see Fig. 2); this was achieved by implementing a small (but NOT negligible) lateral pressure gradient approximation which yields a very elegant and revealing analytical solution. Even better, this approximation appears adatable to the 3-D case we well, which would considerably simplify its more formidable numerical aspects while illuminating the 3-D interactive physics involved. Furthermore, we carried out a detailed study of the available turbulence eddy-viscosity models suitable to the Law of the Wall region in three-dimensional turbulent

boundary layers (this is very important to the inner deck part of our 3-D triple deck approach). One consequence of this was the formulation of a new 3-D Law of the Wall theory for <u>incipiently-separating</u> conditions, which is the appropriate generalization of the Stratford[10] wall velocity profile model at incipient separation in 2-D flow. A parametric study of the resulting universal non-dimensional profile solutions as a function of the basic spanwise-streamwise pressure gradient ratio parameter involved was completed.

During this activity, we maintained a good technical collaboration with Dr. Settles of Princeton including a day-long visit to his laboratory in April. We are making our theoretical developments available to assist, for example, interpretation of his 3-D upstream influence measurements on the swept ramp problem while he in turn has kept us up to date on the experimental findings.

As part of this research effort, technical liaison has also been maintained with certain relevant investigators in Western Europe with whom mutual scientific exchange has proven fruitful in the past (e.g., Professor Klaus Gersten of the Ruhr Universität Bochum-FRG and Dr. H. Stanewsky of the DFVLR-AVA in Göttingen-FRG, Drs. LeBlanc and Ardonceau of the CEAT in Poitiers, France, and Professor Keith Stewartson and Sir M. J. Lighthill of the University of London. Valuable technical discussion of viscous-inviscid interaction phenomena were held with these people during a trip to Europe last March. Moreover, a good contact was established with Dr. Ray Stalker (University of Sydney) who is a pioneer worker on the 3-D interaction problem.

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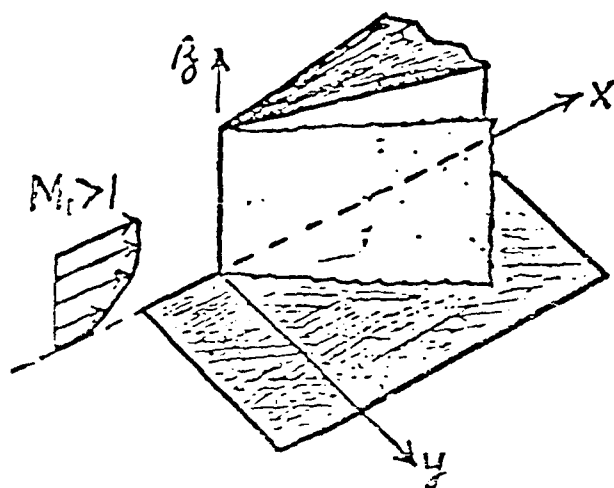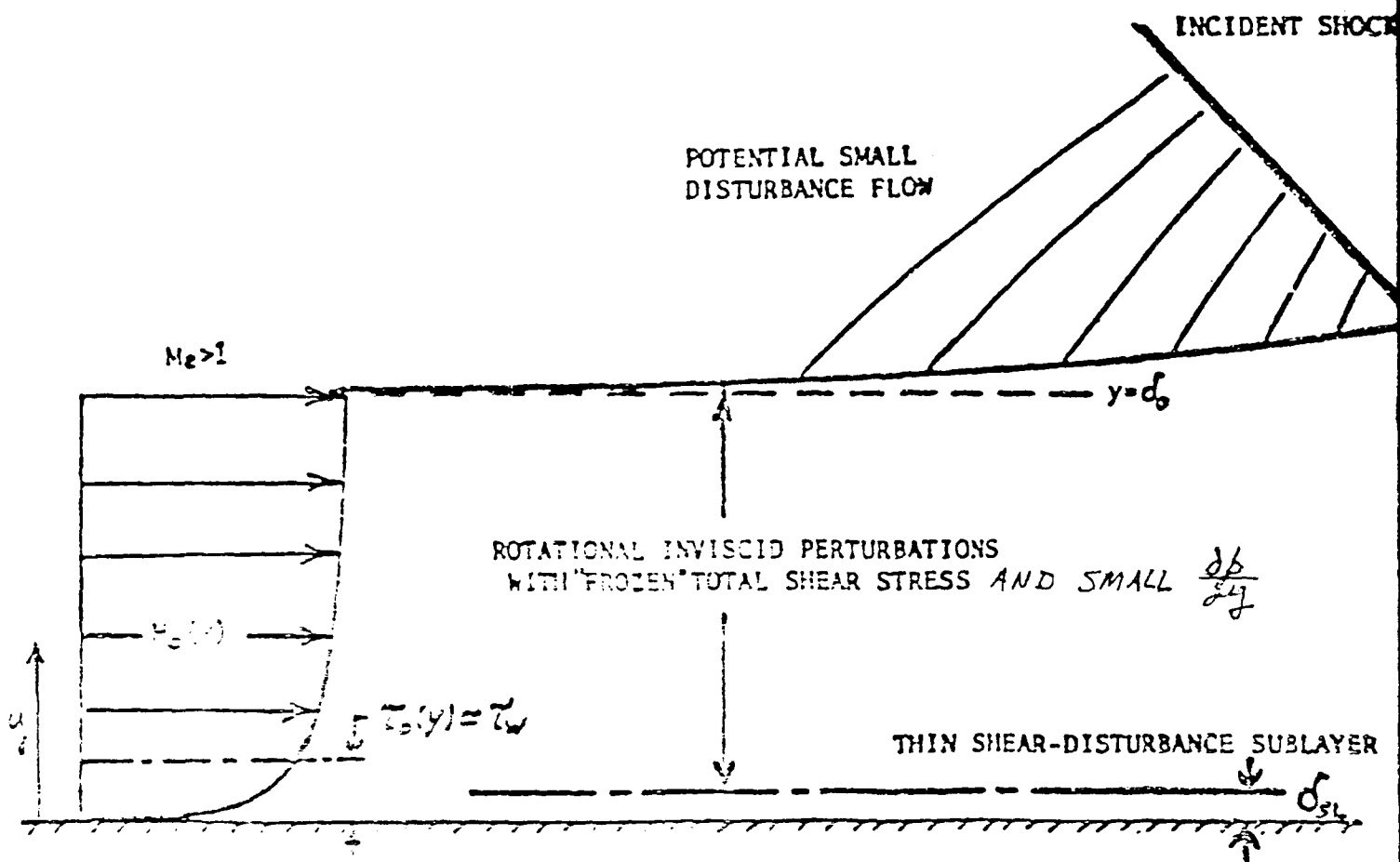
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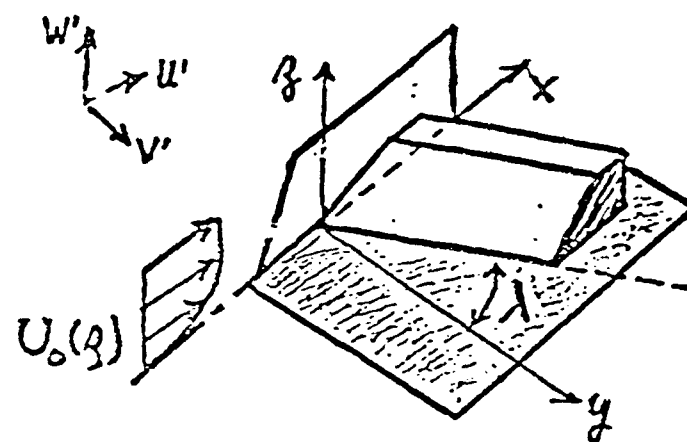
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FIG. 1

Triple-Deck Structure of the Interaction (Schematic)

FIG. 2